Delaying Flowering in Short-Day Strawberry Transplants with Photoselective Nets

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Growing strawberry (Fragaria x ananassa Duch.) transplants under photoselective nets delayed flowering. In August, ‘Strawberry Festival’ strawberry plug plants were grown under red or blue ChromatiNet® or without shading (control) in a glasshouse. Fall flowering response was determined following transplanting into a plasticulture system in the field. The no-shade control plants began flowering in late September and by late November, more than 90% of the plants had bloomed. These plants produced fruit from October to early January. Flowering in plants that were grown under red- or blue-colored shade net did not occur until early January. The results of this study suggested that the use of photoselective shade nets over strawberry plug plants in August blocks the light signal that initiates flowering until the netting is removed, hence, delaying the initiation of flower buds until plants are transplanted in the field.

KEYWORDS Fragaria, plug plant, flower, runner, shade fabric, solar radiation, light modification, light quality

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INTRODUCTION

Control of flowering is important in strawberry (Fragaria × ananassa Duch.) production and the market requirement. In Florida, early blooms are desired in order to sustain winter fruit production. In the mid-Atlantic coast region, growers are motivated to produce fruit for the October–December off-season market window and to increase fruit production for a special occasion like Valentine’s Day, when there is good potential for high monetary returns (Takeda, 1999). Lacking an environment conducive to off-season fruit production, such as the South Coast region of California, strawberry growers in the mid-Atlantic coast region are using plasticulture, high tunnels, day-neutral cultivars, and conditioned transplants to improve early- and late-season strawberry yields (Takeda, 2008). Recently, Takeda and co-workers described an alternative method for promoting early flowering in SD cultivars (‘Chandler’, ‘Carmine’, and ‘Strawberry Festival’), which does require exposure to cool temperatures or SD conditions to flower. More than 80% of transplants of these cultivars were induced to flower in fall if runner tips were plugged into 50-cell trays in early July and maintained in the greenhouse until late August (Takeda, 2008; Takeda and Newell, 2006a, 2006b). In a subsequent study, Takeda et al. (2008) showed that placement of low-intensity red light emitting diode (LED) lamp (maximum wavelength at 662 nm) 1 cm from the crown of strawberry transplants significantly decreased the number of plants that flowered in the fall and delayed flowering. This suggested that regulations of late season flowering through spectral quality could be achieved prior to transplanting.

Spectral filter films and nets with differential light scattering properties and altered proportions of R/FR ratio have been used as a nonchemical means of growth control in horticultural crops (Fletcher et al., 2005; Shahak, 2008). Normally shade nettings are used to mitigate temporary heat-induced cessation in reproductive growth (Wagstaffe and Battey, 2008), but placing photoselective greenhouse films over strawberry plug plants in September did not significantly affect flowering time and resulted in reduced early and total-season yields than commercially produced transplants (Black et al., 2005).

Environmental manipulations are useful for delaying or suppressing the time to flowering. Stock chrysanthemum plants were kept vegetative by long-day, or with night breaks (Kofranek, 1980), and flowering in sugar canes was suppressed during September to ensure that plants remained juvenile by night-break lighting when day lengths were conducive for floral bud induction (Moore, 1985). Also, flowering was delayed or inhibited by high temperatures on strawberries (Wagstaffe and Battey, 2008) and low irradiance levels on rose shoots (Mor and Halevy, 1980). Light quality can be manipulated with colored shade nets (e.g., ChromatiNet®, Polysack USA, Inc., San Diego, CA, USA) for promoting specific physiological responses in horticultural crops (Shahak et al., 2004).
The objective of this study was to determine the subsequent growth and flowering response of strawberry plants in the field after transplants were grown under photoselective nets for one month.

MATERIALS AND METHODS

On June 30, 2008, runner tips of the ‘Strawberry Festival’ strawberry (Chandler et al., 2000) purchased from a nursery (Lassen Canyon Nursery, Redding, CA, USA) were plugged into 50-cell pack trays (∼320 transplants·m⁻²) and misted under intermittent sprinklers for 10 days to promote rooting in a greenhouse located at the Appalachian Fruit Research Station, Kearneysville, WV (lat. 39°N). Afterwards, all trays were placed on a greenhouse bench and watered and fertilized as needed. On July 31, 2008, four trays of ‘Strawberry Festival’ transplants were placed under a 1.2-m high, 2.2-m long, and 1-mt wide frame erected on the greenhouse floor and on which two layers of colored, light-transmitting shade netting material (ChromatiNet® Red Shade Net 30%, Polysack USA, Inc.) were draped. Four trays of ‘Strawberry Festival’ were placed under a second frame that was covered with two layers of ChromatiNet Blue Shade Net 30%. The control plants were retained on the bench unshaded. All trays were fertigated daily with 140 mg NO₃·L⁻¹ H₂O, which was drained after 30 min. On August 29, 2008, transplants were established 30 cm apart atop raised beds at the University of Maryland Wye Research and Education Center in Queenstown, MD (lat. 38.5°N, USDA Plant Hardiness Zone 7a) after the methods described by Poling (1993). A high tunnel (14.5 m long × 6.4 m wide, manufactured by Ledgewood Farm Greenhouse Frame, Moultonborough, NH, USA) was erected over the plants on October 17 and covered with a 4 mil infrared greenhouse film (Tufflite Infrared™, Covalence Plastics, Minneapolis, MN, USA). A hive of bumble bees (Koppert Biological Systems, Romulus, MI, USA) was placed in the tunnel in November for pollination. The plants were covered with a heavy row cover whenever the temperature was expected to drop below 2°C. Plants with open flowers and fruit were counted at the end of September, October, and November 2008, and in early January 2009. Ripe fruit were harvested at weekly intervals from September to December 2008 and from March to May 2009. In summer 2009, the study was repeated, but the transplants were covered with only one layer of light-transmitting shade netting material (ChromatiNet® Red and Blue Shade Net 30%, Polysack USA, Inc.). The field experiments in both years were a randomized complete-block experimental design with four 8-plant replications. The raw flowering percentage data were transformed using the arcsine-square root transformation before statistical analysis and subjected to an analysis of variance using PROC GLIMMIX, which uses generalized linear models with a link function to model the binary response where an individual plant either flowered or
not at a given time (SAS Institute, Cary, NC, USA). This approach allowed modeling of the repeated measures aspects of the study.

RESULTS AND DISCUSSION

Plants have evolved mechanisms to alter their growth and development in response to environmental signals. The transition from vegetative to reproductive development in strawberries is regulated by a number of environmental factors (Darrow, 1966). Conditioning treatments for plug plants, such as exposure to specific high and low temperatures (Bish et al., 2004) or low temperatures and short-day (SD) photoperiod (Durner, 1999; Heide, 1977; Oda, 1989), have been described for hastening flowering in SD strawberry transplants. In this study, three groups of ‘Strawberry Festival’ strawberry transplants were subjected to the propagation scheme previously described (Takeda and Newell, 2006a; Takeda et al., 2008) that induces fall flowering. To block specific wavelengths (blue and green or green and red), two groups were placed under either blue- or red-colored shade nets while a third group (control) was left unshaded.

In the unshaded control plants, flower buds started to emerge in September 2008 (Table 1). By December, more than 90% of the control plants had flowered. The control plants produced 141 g of fruit (15 g average fruit weight) between October and early January and 560 g per plant from March 10 to May 14 (Fig. 1). Vegetative growth in the form of runner production averaged six runners per plant in September, decreasing to about three in October then none after that. In contrast, the ‘Strawberry Festival’ strawberry plants that were subjected to the same propagation scheme but were under two layers of 30% blue- and red-colored shade nets in August did not flower until January. The runneri ng resulted in an average of five runners per plant in September decreasing to four in October and then no more in the following months. In spring, plants that were held under

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<tr>
<td>Red</td>
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<td>4.2 b</td>
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<tr>
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<td>3.7 a</td>
<td>0 a</td>
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<td>2.7 a</td>
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<th>Oct. 28</th>
<th>Nov. 25</th>
<th>Jan. 5</th>
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<td>0 a</td>
<td>0 a</td>
<td>69 a</td>
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<tr>
<td>Blue</td>
<td>0 a</td>
<td>0 a</td>
<td>0 a</td>
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<td>47 b</td>
<td>80 b</td>
<td>91 b</td>
<td>100 b</td>
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*(300 Plants/m²) for one month under ambient light conditions or under two layers of red- and blue-colored shade nets, before planting in annual plasticulture system on August 28, 2008. Runners were counted and removed at the end of September, October, and November in 2008. Plants with open flowers in each plot were recorded at about monthly intervals.

Letters show significant differences within a column at \( P \leq 0.05 \). Mean separation was performed using arcsine transformation.
colored shade nets produced about 500 g per plant (Fig. 1). Growing transplants in August under only one layer of either blue or red Chromatinet colored net had less effect on fall flowering (Table 2).

Placement of transplants under colored shade nets in August delayed flowering until January, but had little or no effect on fall runnering in both years. Colored shade net treatments slightly decreased the amount of fruit produced from March to May. These findings suggest that the plug transplants respond to environmental cues besides SD photoperiod and low temperatures to bring about flower induction and inflorescence differentiation in August when the day lengths are more than 15 hr long and temperatures are above 22°C. Colored shade nets modify the spectrum and amount of light transmitted to the transplants (Shahak et al., 2004). The ability to vegetatively grow and produce stolons was not affected by shading.

![Figure 1](image)

**FIGURE 1** Effect of shade treatment in August on yield of ‘Strawberry Festival’ strawberry plants during fall 2008 and spring 2009 in high tunnel culture.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Runners (no./plant)</th>
<th>Flowering plants (%)</th>
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<tbody>
<tr>
<td></td>
<td>Oct. 2</td>
<td>Nov. 4</td>
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<tr>
<td>Red</td>
<td>4.7 b</td>
<td>3.3 a</td>
</tr>
<tr>
<td>Blue</td>
<td>4.6 b</td>
<td>3.1 a</td>
</tr>
<tr>
<td>No shade</td>
<td>3.8 a</td>
<td>3.3 a</td>
</tr>
</tbody>
</table>

*(300 Plants/m²) for one month under ambient light conditions or under one layer of red- and blue-colored shade nets, before planting in annual plasticulture system on August 29, 2009. Runners were counted and removed in October and November 2009. Plants with open flowers in each plot were recorded in October and November. Letters show significant differences within a column at \( P \leq 0.05 \). Mean separation was performed using arcsine transformation.
transplants in August. Also, the results of this and prior studies (Takeda and Newell, 2006b) indicated that flowering and fruit development does not have a deleterious effect on spring crop. Spring yields of plants that were summer shaded and did not crop in fall were sometimes less than those plants that were unshaded in summer and fruited in fall (Fig. 1). In South Carolina, neither marketable yield nor fruit sugar content was increased for ‘Sweet Charlie’ strawberry in a forced fall/winter cropping system under ChromatiNets (Dufault and Ward, 2009a, 2009b). These authors concluded that lower ambient light intensity from fall to spring overwhelmed any enhancement from changes in light quality provided by ChromatiNets. In Israel where light intensity is quite high in the winter, Shahak (2008) reported that the performance of strawberries in annual plasticulture was improved by growing them under photoselective nettings.

Durner et al. (1984) reported that flower bud formation in SD strawberries occur under a photoperiod >12 hr provided temperatures were below 16°C. In the mid-Atlantic coast region, flower bud initiation in SD cultivars occurs in fall when the photoperiod shortens to 11–13 hr (Darrow, 1966; Waldo, 1930). About 16 to 21 days of short photoperiods are required for flower bud initiation (Guttridge, 1969; Sonsteby and Nes, 1998; Verheul et al., 2006), and plants flower after 47 days from the end of the SD treatment. For strawberry plants that flowered around October 1 (Table 1), flower bud formation would have occurred in mid August. The evocation that commits a bud to become reproductive would have occurred even earlier. Covering transplants with two layers of colored nets as described in this study prevented the further development of the flowers. Since all transplants had or were flowering by January, the new floral buds must have formed in plants treated with photoselective colored net once the plants were exposed to the natural short days in the field. The results of the present study showed that, by maintaining plug plants under two layers of red and blue photoselective colored nets in August, flowering could be delayed until January. Growing the transplants under one layer of 30% red and blue ChromatiNet colored nets delayed flowering somewhat (Table 2). These findings support a previous work that showed red light (600–700 nm wavelengths), used for day-extension or night-break lighting and low irradiance during the floral inductive period inhibited or delayed the early stages of flower bud differentiation in SD plants (Rees, 1987).

In strawberries, vegetative reproduction is the primary process used by nurseries for propagating plants. Strawberry plants multiply vegetatively via stolons (runners) that develop into daughter plants (Darrow, 1966). Flower buds are removed from mother plants in strawberry nurseries to prevent flowering and fruiting stress on the plant and to promote runner production. Also, flowers and fruit are normally detached to reduce infection by Colletotrichum species, the primary causal agent of strawberry anthracnose crown and fruit rot. An occurrence of this disease in nursery beds may result in serious losses on fruit production farms where infected plants may
eventually die from vascular collapse or provide the inoculum to start flower and fruit infections the following spring (Sjulin, 2008).

The colored net treatment in August had little or no effect on runnering during fall months in ‘Strawberry Festival’ strawberry plants. Both control plant and plants that were grown under red and blue photoselective nets produced about seven to nine runners from September to November (Tables 1 and 2). This is significant to the strawberry transplant/nursery industry as a non-chemical means for preventing or delaying blooms without affecting runner production. Early in the season, it is easy for workers to walk through the nurseries and remove the flowers and berries. Later in the summer when daughter plants start to root, tractor and human traffic must be limited to prevent damage to the daughter plants and stolons. In these situations, tractors equipped with side booms to cover several rows with workers suspended over the strawberry plants in sling/harness or in sleeping bag-like contraptions are used for detaching flowers and fruit (Sjulin, 2008). Nursery flower removal operation is estimated to cost about $500 per acre (D. Marcum, University of California Cooperative Extension Service; personal communication). An alternative plant propagation scheme for producing non-flowering stock plants may involve the establishment of the stock plants in protected environments in late winter to produce runners in the spring. Plug plants that are produced from these runner tips can be grown under a red- or blue-colored shade net for one month before field establishment. Also, the technique described here for delayed flowering may also be useful for mid-winter fruit production or in a programmed fruit production system in a protected environment to maximize yield at special occasions like Valentine’s Day when the price for strawberries is high (Durner, 1999; Takeda, 1999). Additional studies are warranted to determine whether these colored nets can prevent or delay bloom in day-neutral strawberries and to better understand the relationship between levels of selective light transmission and flowering response in short-day strawberries.

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LITERATURE CITED


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